

# **Tensor Fluxgate Gradiometer Development**

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## **LONG TERM GOAL**

Our long-term goal is to provide a robust suite of algorithms capable of performing real-time localization of both isolated and grouped ferromagnetic targets. It is intended that these algorithms be applicable to any tensor magnetic gradiometer system used for surface or subsurface platforms. These algorithms will be most robust when used in conjunction with conventional navigational systems, but will be provided with a self navigating capability that exploits the magnetic fields and gradients of the sources being localized.

## **OBJECTIVES**

The objectives of this task are (1.) to use the prototype tensor fluxgate gradiometer, developed by Quantum Magnetics as a phase I SBIR product, to collect an extensive data base for a variety of ordnance and standard magnetic sources under a variety of conditions, (2.) to refine, extend, and create algorithms for both point-by-point homing and precision mapping of magnetic sources, (3.) to evaluate and fine tune the algorithms using the established data set, and (4.) to produce a self contained user friendly computer code for application with the planned Quantum Magnetics SBIR phase H product as well as superconducting gradiometers developed at the Coastal Systems Station.

## **APPROACH**

Over a period of several years a low level independent research effort has succeeded in developing several algorithms, some of them patented or in the process of being patented. These algorithms are capable of converting magnetic gradient data into information about the magnetic moment vector, position vector, and relative motion of sensor and source. When precise navigational information is available, these algorithms are expected to be relatively easy to implement, and to investigate this mode of operation we have incorporated a differential GPS sensor mounted on a cart along with the tensor gradiometer.

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Absent a navigational capability, the localization process is much more difficult. It would be highly desirable if magnetic sources could be precisely located relative to the operator using only magnetic information generated by the source. Considerable progress has been made in connection with this latter problem, but much remains to be done. One of the most critical issues has been and remains the determination of the absolute orientation of the magnetic sensor platform in space. This knowledge is essential both to the removal of the effects of natural background magnetic gradients, and to the correction of the magnetic gradients of a target source during final localization.

To date, our efforts have focused on the use of accelerometers to augment the measurement of the earth's magnetic field vector and provide absolute orientation. This effort has had limited success, but our analysis of the data is not complete, and we are investigating the use of either accelerometer arrays or rate gyros to establish the platform orientation by integrating the platform angular velocity vector, at least for limited time periods.

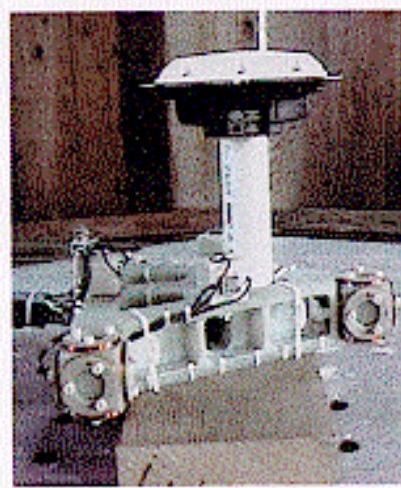
## WORK COMPLETED

Before data collection could begin we had to specify and procure a wide dynamic range data collection system and a suite of ancillary sensors. A complete data acquisition system consisting of a state-of-the-art personal computer, multi-channel digitally controlled, anti-aliasing filter and a twelve channel, high-resolution VXI analog-to-digital converter was purchased and installed in an instrumentation shack. This instrumentation shack was located convenient to both the sensor test area and the motion tables used for the High Tc and Low Tc superconducting gradiometer evaluations. The cost of the acquisition system was shared by both projects.

The required data collection software was written in the HP Vee visual programming language. This language is intended to be the vehicle for the final general software system, including O1 data preparation, signal processing, algorithm execution and display. The language lends itself to the easy incorporation of Dynamic Link Libraries (DLLS) common to Windows applications, and a considerable effort has been made in this time period to learn to write existing algorithms in this form for easy incorporation.

An extensive collection of both background and target data has been compiled using the phase I Room Temperature Gradiometer (RTG). We have leased a differential GPS system for precision mapping and purchased a suite of three-axis accelerometers for use in the determination of absolute platform orientation. We have completed a variety of experiments with simultaneous measurement of the background earth's magnetic field vector and the acceleration vector at three points on the platform. We have established an array of ordnance items and standard magnets and have collected a large database of runs both with the sensor hand held and mounted on a cart with the GPS sensor. The runs have ranged from direct overpass up to 30 feet laterally from the target array.

Early problems with the GPS sensor led us to move it from its original position on the RTG as seen in Figure 1 and place it on a seven foot mast on the cart as seen in Figure 2. Our original belief was that the operator was interfering with the differential operation of the system causing the precision mode to drop out intermittently. We have since discovered that there was an intrinsic problem in the rf link of the GPS system, and we intend to revisit the placement of the antenna as seen in Figure 1.



**Figure 1. Hand carried RTG sensor with GPS antenna and accelerometers**

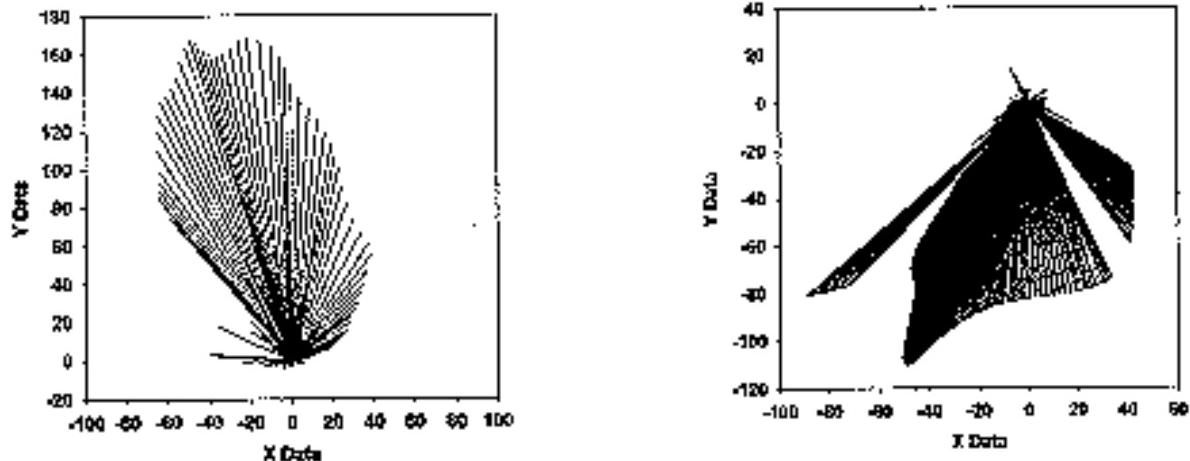


**Figure 2 Cart-mounted RTG with GPS**

We have written a computer program to exercise the latest interactive magnetic homing algorithm and are using it to analyze the performance of the RTG in the handheld mode. We have developed a new idea for magnetic localization in the hand held GPS free mode in which windows of data are to be used and navigation is to be accomplished from the magnetic data itself. This work is very preliminary. Finally, we have begun work on the use of windowed data used in conjunction with navigational data for precise mapping of magnetic targets. This mode promises to be more noise tolerant than the point-by-point algorithms, and will be usable with multiple targets. We will use cues based on point-by-point analysis to seed this processing algorithm and make it more efficient. This method of processing is lower risk than the other algorithms mentioned, and will provide a robust capability when navigational information is available.

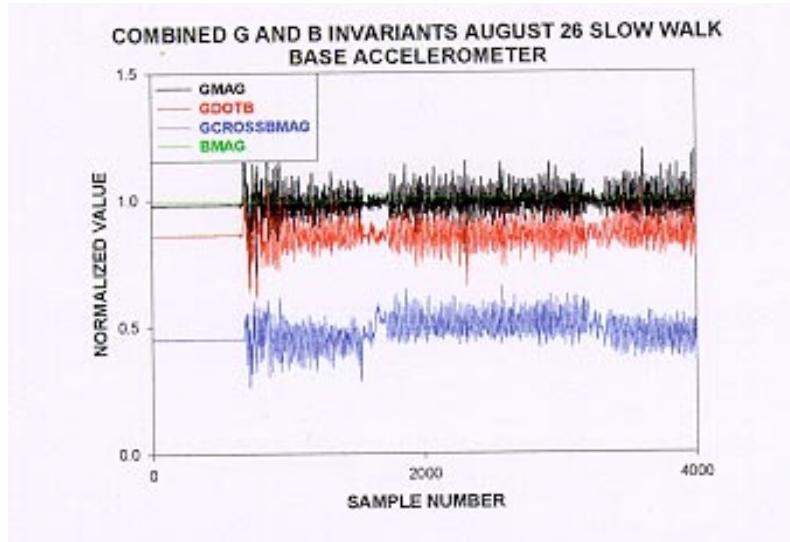
## RESULTS

The most recently completed localization algorithm uses the magnetic gradient tensor and its time rate of change to uniquely determine the bearing vector to the source, the direction of motion of the sensor relative to the source, and the orientation of the source moment vector. This permits instantaneous homing to the target when the observer can access the homing information. Figure 3. shows the horizontal projection of the bearing vector, scaled by the magnitude of the gradient tensor(nT/ft), seen by the observer as he moves from right to left with a magnet source comparable to a 1000 pound iron bomb 10 feet away on his right. The rays evolve in time in a clockwise sense. Figure 4. shows a similar result for an observer moving from left to right with a 105 mm shell 4 feet to his right and 3 feet down. Here the rays also evolve in a clockwise sense. The broken pattern seen in Figure 4. illustrates a fundamental problem with this process. The algorithm is based on the assumption of translational motion, and rotation of the sensor in the target gradient contaminates the data and causes errors,



**Figure 34. Gradient-scaled bearing vector**

We attempted to correct for rotational motion of the sensor by including a vector accelerometer on the sensor body. If one can measure the true gravity vector, then this can be coupled with knowledge of the earth's background magnetic field vector to uniquely determine orientation in space. However, we discovered that the inertial accelerations associated with walking or cart motions are a significant fraction of earth's gravity, and the orientation of the gravity vector can not be determined with sufficient accuracy. We illustrate this problem in Figure 5 where we show, for a platform carried by a slowly walking person, the four rotationally invariant quantities associated with the earth field vector and acceleration vector. The quantities are the field magnitudes, the projection of one field vector on the other, and the magnitude of the vector cross product of the two fields. If there were no inertial accelerations, the traces shown would be flat. In future work, we will investigate rate gyros and/or accelerometer arrays and their use in platform orientation determination,



**Figure 5. Inertial effects on rotational invariants for a person walking slow.**

## **IMPACT/APPLICATION**

This demonstration of localization using magnetic signature information allows instant stand-off mapping without the need for elaborate grid searches. It will allow the safe avoidance of potentially dangerous targets while providing accurate mapping in a real time scenario.

## **TRANSITIONS**

The currently funded effort scheduled to be completed at the end of FY99 will provide a complete set of localization/tracking algorithms compatible with a variety of magnetic gradiometers. Originally, the planned transition using the RTG sense package would have been the Diver Portable Buried Mine Hunter Task under the Mission Support Project CSS#20114. However, this year that effort was refocused to develop only sonar technology and a new proposal for accomplishing the required sensor fusion remains unfunded at this time. Because of the generic nature of magnetic tracking/localization, a large number of additional areas and applications are being considered, such as UneXploded Ordnance (UXO) localization and Autonomous Underwater Vehicle (AUV) applications. While the delivered algorithms will be specifically tailored to the RTG sensor in terms of gradient requirements and sensor sensitivities, they are easily adjusted to a range of sensors providing magnetic gradient data. At the end of FY99 with the delivery of the SBIR Phase II man-portable sensor from Quantum Magnetics combined with the software developed under this task will provide an unexcelled standoff detection/localization system for the localization and mapping of UXO and other land based targets. Underwater applications will require limited modifications to replace the GPS data with suitable underwater navigational information as well as other changes to accommodate the required platform.

## **RELATED PROJECTS**

The CSS Magnetic Sensors project #21325 is developing a liquid nitrogen based, superconducting gradiometer system capable of detecting ferromagnetic underwater objects from a moving platform. It has greater projected sensitivity but is not man portable and will require cryogenic fluid. Some of the localization code being developed in this task will be applicable to that activity with some modification.

## **REFERENCES**

None.

## **PUBLICATIONS**

Patent: "Method of Magnetic Source Localization using Gradient Tensor Components and Rate Tensor Components", by W. M. Wynn, U. S. Patent Number 5,777,477 July 7, 1998